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ABSTRACT

Sunlight (solar radiation) provides many beneficial contributions to mankind, including warmth and energy, vision and photoresponses, photosynthesis, and vitamin D synthesis. Along with these positive benefits attributed to solar radiation, there are also adverse effects. A particular adverse effect of current interest and concern which is addressed in this module, is over-exposure of human skin to solar radiation. The module is divided into four main topical categories: (1) the nature of, and how to detect, the presence and/or absence of radiation; (2) atmospheric filtering of solar radiation (considering photo ionization and photo disassociation); (3) adverse effects on human skin of over-exposure to solar radiation; and (4) commercially available products which claim to protect against over-exposure, and how to test the effectiveness of these products. Included within these categories are activities in which students build a spectroscope; measure the wavelength of radiation observed with the spectroscope; and use the instrument to establish the existence of ultraviolet radiation, observe broad band absorption, and observe radiation absorbed by commercially available sunscreens. The module, which contains the equivalent of 1 week's work for introductory college or advanced high school physics courses, concludes with a summary section. Suggestions for further study and discussion questions are included in this section. (JN)

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SUNBURN AND SUNSCREENS

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TABLE OF CONTENTS

INTRODUCTION 1

SEGMENT I 3
ELECTROMAGNETIC RADIATION AND SPECTROSCOPE PROJECT..... 3
Wavelength and Frequency 4
Electromagnetic Spectrum 6
Diffraction of Mechanical Waves..... 7
Diffraction of Light 8
Diffraction Gratings 10
Spectroscope 11
Solar Spectrum 12
Detecting Ultraviolet Light..... 13
Measuring the Wavelengths of Light 15
Questions - Segment I 18
Segment I - References 20

SEGMENT II
THE EARTH'S ATMOSPHERE AS A FILTER OF SOLAR RADIATION 21
Photoionization 24
Photodissociation 25
Questions - Segment II 30
Segment II - References 32
SEGMENT III
SKIN DAMAGE CAUSED BY SOLAR RADIATION AND SUNSCREENS 33
Skin 33
Sunburn 35
Long Term Effects 36
Prevention of Damage 38
Sunscreens 38
Student Investigation 42
Comparison Project 42
Questions - Segment III 44
Segment III - References 45

SEGMENT IV
LABORATORY PROJECT: RELATIVE EFFECTIVENESS OF
COMMERCIALLY AVAILABLE SUNSCREENS 46
Introduction 46
Objectives 46
Method I: Absorption Spectroscopy with Monochrometer 48
Method II: Absorption Spectroscopy with Shoebox
Spectroscope 54

SEGMENT V
SUMMARY AND DISCUSSION QUESTIONS 56
For Further Study 58

INTRODUCTION

Life, as we experience it, would be impossible without light from the sun. Therefore, we can accept, with categorizing and explaining in great detail, that sunlight (solar radiation) provides many beneficial contributions to mankind. Some of these are warmth and energy, vision and photoresponses, photosynthesis, and vitamin D synthesis.

Along with the positive benefits attributed to solar radiation, there are also adverse effects. A particular adverse effect of current interest and concern is over-exposure of the human skin to solar radiation. The particular solar radiation, the adverse effects of it on human skin, and ways to protect ourselves from over-exposure are the issues we wish to address in this module.

The module is divided into four main topical categories: (1) the nature of, and how to detect the presence and/or absence of radiation, (2) atmospheric filtering of solar radiation, (3) adverse effects on human skin of over-exposure to solar radiation, and (4) commercially available products which claim to protect against over-exposure, and how to test the effectiveness of these products.

This module is designed to help you meet two learning objectives. The primary objective is for you to participate in the process of scientific inquiry. To meet this objective you will build a spectroscope, measure the wavelength of radiation observed with your spectroscope, use your spectroscope to establish the existence of ultraviolet (UV) radiation, observe broad band absorption, and observe radiation absorbed by commercially available sunscreens.

The secondary objective of this module is that of enabling the reader to

further pursue the issues raised here, and other related issues. Scientists have an obligation to investigate issues of society and to inform society of their results, so as to improve health and safety standards. Such related issues might include government regulation of sunscreens, faulty or misleading advertising by manufacturers, the hazards of tanning salons, and the deterioration of the protective ozone layer of our atmosphere by certain pollutants. These related issues will be discussed in greater detail in the final segment of the module.

The background required for completion of this module depends somewhat on how thoroughly the reader wishes to absorb the material. We feel that the overall reading level is suitable for high school or early college use. Many technical terms normally defined in introductory Physics courses are used in this module, so that a student having such a background would have some advantage. However, in most instances, technical terms are clearly defined or described, so that a reader lacking a proper background should have few, if any, difficulties. Mathematically, some knowledge of basic trigonometry is helpful, but not essential.

SEGMENT I ELECTROMAGNETIC RADIATION AND SPECTROSCOPE PROJECT

It is quite apparent that the sun emits light, which is only a narrow region of a much broader phenomenon known as electromagnetic radiation. It is not so apparent, nowever, that non-visible radiations are also emitted by the sun. This segment deals with all of the radiation emitted by the sun which is called electromagnetic waves, because it consists of electric and magnetic fields which travel together as waves. They can be described by their measurable frequencies and wavelengths. They transport energy, propogate a perturbations, superpose; diffract, interfere, and refract as mechanical waves. Yet electromagnetic waves do not require a medium to propogate (or we would not be getting any of the electromagnetic waves emitted by the sun).

Because some of their characteristics are more apparent to you, we will first briefly discuss wave properties with mechanical waves, then go on to a description of the electromagnetic spectrum and finally discuss some diffraction. Following this we will use the property of diffraction to identify and measure some wavelengths of light.

Wavelength and Frequency

Waves that we normally observe, such as water waves and waves on a rope, have a wavelengtn which can easily be measured. In Figure 1.1 is a "stop action" image of a wave.

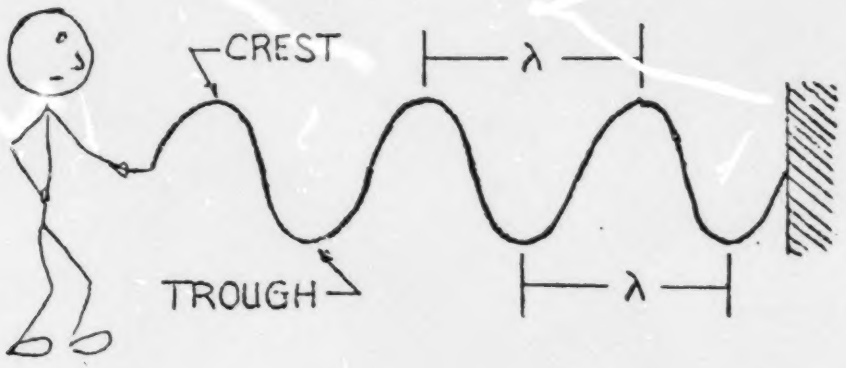


Figure 1.1

A wavelength (λ) is the linear distance between two adjacent points in phase, for example two adjacent crests or two adjacent troughs along the wave.

The frequency (f) of the wave in Fig. 1.1 would depend upon the wave source. The number of full cycles generated per unit of time is the frequency. In one full cycle, the wave moves forward by a distance equal to a wavelength. The amount of time elapsed is called period. The period is the inverse of the frequency. They are related by

$$\lambda f = v$$

where λ is wavelength, f is frequency (usually measured in sec^{-1} = Hz) and v is the wave speed.

Sample problem: Derive $\lambda f = c$

Sol: $v = \frac{\Delta x}{\Delta t} = \frac{\lambda}{T} = \lambda f$

Sample problem: Wave crests 0.5 m apart are being propagated in a rope. These waves travel at a speed of 2m/s. What is the frequency of propagation?

Solution:

$$f = \frac{v}{\lambda} = \frac{2m/s}{.5m} = \frac{4}{s} = 4s^{-1} = 4Hz$$

This means that the waves are being propagated at a frequency of 4 cycles every second.

The speed of a wave depends on properties related to the medium in which the wave travels. For the above example, waves of any frequency generated in the rope would have the same speed. Therefore, the wavelength changes if the frequency does.

Electromagnetic waves also have a measureable wavelength and frequency. The formula for calculating frequency in an electromagnetic wave is the same as for any other wave, provided the wavelength and speed are known. For electromagnetic waves, as opposed to mechanical waves, the speed is enormously high. The speed, represented by "c", is about 3×10^8m/s in a vacuum. In order to calculate a frequency from a wavelength, simply divide:

$$f = \frac{c}{\lambda}$$

where once again the frequency is in s^{-1} or Hz.

Sample Problem:

The wavelength of yellow light travelling through a vacuum is 6×10^{-7}m. Find the frequency of yellow light.

Solution:

$$f = \frac{c}{\lambda} = \frac{3 \times 10^8 m/s}{6 \times 10^{-7} m} = 0.5 \times 10^{15} s^{-1} = 5 \times 10^{14} Hz$$

Naturally, the same equation can be used to find either c or λ.

Electromagnetic Spectrum

Visible electromagnetic radiation falls in a range of wavelengths from 4 x 10^{-7}m to 7 x 10^{-7}m. This represents a frequency range of 7.5 x 10^{14}Hz to 4.3 x 10^{14}Hz. The sun emits radiations covering a much wider span than this. Since the primary issue of this module is related to some of the invisible radiation, we will look briefly at the range of solar radiations, and in the next segment we will discuss those which are of most concern to use.

In Fig. 1.2 is a representation of the electromagnetic spectrum. The frequency and wavelength are both shown on logarithmic scales. A linear representation would provide very little detail at the low frequency end since the values would be comparatively closer together there than toward the high frequency end. From lower to higher frequencies on the chart there is a tendency toward greater physical danger upon contact. Gamma rays are highly penetrating and known to destroy or severly damage skin and other bodily tissues. X-rays are less penetrating and less harmful than gamma rays, but are still known to do irreversible damage to tissues, and are or should be used only with great precaution in medicine. Ultraviolet (UV) is far less damaging than higher frequency radiations, but once again prolonged exposure to the skin or brief exposure to the eyes can produce irreversible adverse effects. Visible light is not considered harmful to the skin, but may be damaging to the eyes, depending upon the time of exposure and the intensity of the light. The intensity of frequencies less than those of visible light which the sun emits are not considered dangerous to bodily tissues. Since our intent is to discuss the sun's harmful radiations, these lower frequencies are of no real concern in this module.

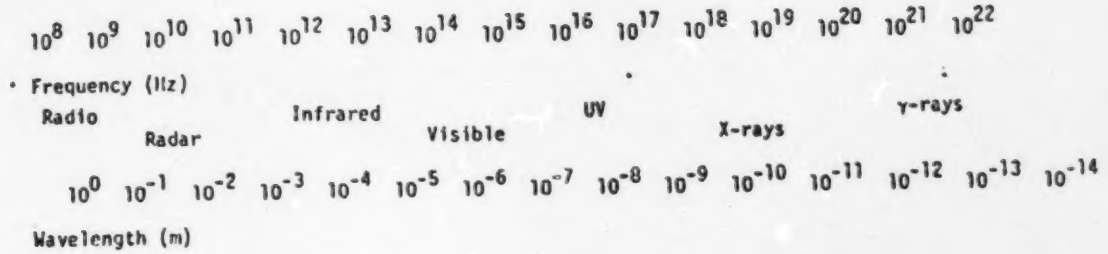


Figure 1.2

Electromagnetic Spectrum

Diffraction of Mechanical Waves

As wave fronts approach a barrier or a slit of the size of approximately one wavelength, the waves will pass through the opening and bend around its edges. The amount of wave bending that occurs depends upon the size of the opening relative to the wavelength. If the opening is many wavelengths wide, the bending is very slight, possibly imperceptible. As the opening gets smaller and smaller, to where it is about one wavelength or less across, the bending gets progressively greater. Figure 1.3 gives two extremes of this.

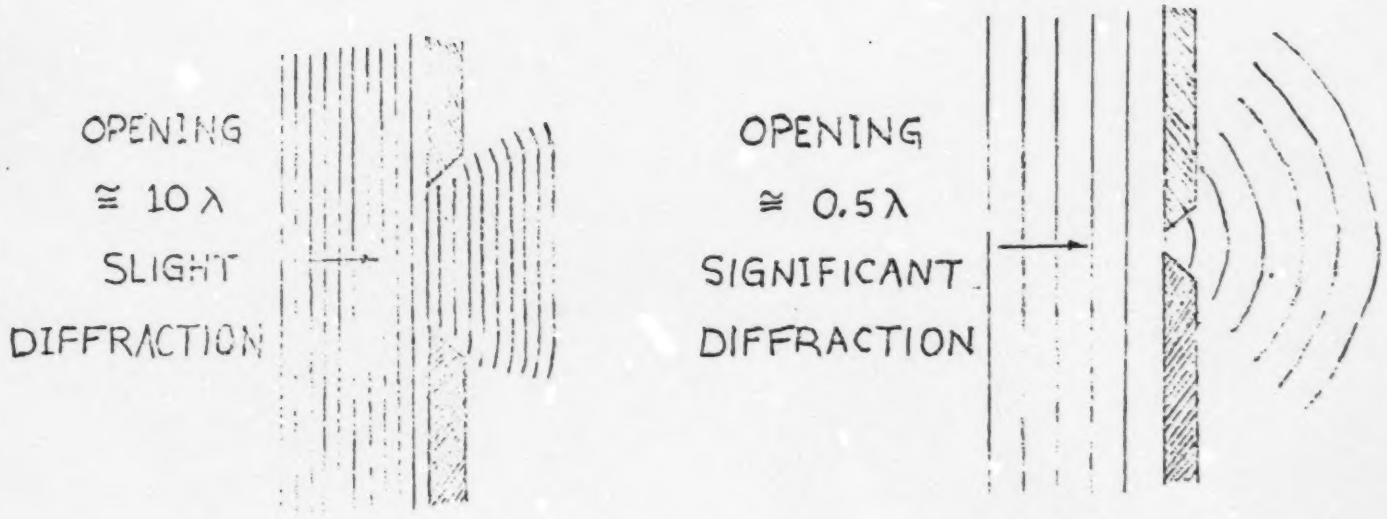


Figure 1.3

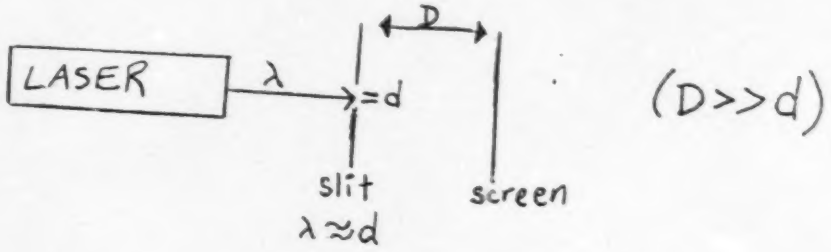
This bending around barrier edges is referred to as diffraction. Diffraction of water waves can be observed on large lakes and oceans where breakwaters have been installed. Behind the breakwater (in the shadow region) a great deal of rippling can usually be seen. Diffraction can also be observed with sound waves. The fact that voices can be readily heard from around corners, and even from several rooms away, is evidence that the sound waves are bending around various corners to reach the listener.

Diffraction of Light

One of the wave properties that electromagnetic radiation exhibits is that of diffraction. As with mechanical waves, the smaller the opening compared to the wavelength, the greater the diffraction. If from a brightly lit room you open the door a few centimeters and observe the room light shining into an adjacent dark hallway, the light would not appear to diffract at all. This, of course, is due to the fact that a few centimeters represents about 10^5 wavelengths of light. The opening is large compared to the wavelengths, thus no diffraction is observed.

How can you observe the diffraction of visible light? The obvious solution is to make a slit much smaller than a few centimeters, pass light through the slit, then observe the light after it passes through the opening.

If your Physics Department has a laser available, you might ask your physics teacher to set up the arrangement below:



Observe the pattern on the screen. Notice that there is a wide "central maximum" with bright "patches" separated by dark areas on each side of the central maximum. The dark areas are produced by the destructive interference of light waves at those points. More pertinent to the point of this discussion is to notice that the pattern is much wider than the opening of the slit. This is caused by diffraction.

The width of the central maximum is a function of the wavelength (λ), the slit width (d), and the screen-slit distance (D). For a constant d and D, the width will depend only on the wavelength of the light. Larger wavelengths will be diffracted more than smaller wavelengths, resulting in larger central maxima.

There are other observations that can be made to demonstrate the diffraction of visible light. For example: (1) Look through a window screen towards a mercury-vapor street light at night. Notice the "cross-like" pattern produced. (A similar pattern can be observed by looking at a street light through a fine woven cloth such as a curtain or handkerchief cloth.)

2) Have you ever noticed small distortions or "squiggles" in your field of vision? These can be caused by light diffraction around small dust particles on the lens of your eye.

3) The resolution of two light sources that are so far away from you that you cannot tell whether it is one or two sources -- is limited by diffraction. If the sources are circular, you may see diffraction disks as light passes through the lens opening of your eye. In order to resolve two far away circular sources, their diffraction patterns must not overlap much: the amount of overlapping that still allows to clearly recognize two sources is called "resolution criterion".

4) The resolving power of a microscope is limited by the wavelength of light. When significant diffraction occurs (as happens with small objects) resolution is lost. Electron waves are often used (instead of light waves) to observe small objects in the electron microscope.

5) The resolution of images seen in telescopes is limited by the diffraction produced by the lenses. Diffraction effects of very distant objects are significant (since their image is so small). This also depends on the size of the lens. The smaller the image formed by the lens, the less resolution is obtained.

Diffraction Gratings

A diffraction grating is made by finely scratching thousands of closely spaced parallel grooves into a piece of glass or some other transparent material. Inexpensive replicas are molded out of plastic and are readily available from suppliers. e.g. (Edmund Scientific Company, 6885 Edscorp Bldg., Barrington, New Jersey 08007.)

These gratings multiply diffract incoming light, since each groove acts like a small opening in a barrier. The effect of these multiple diffractions is that the diffracted light is much better separated into its component colors. A diffraction grating can be used to take visible light (or a wider range of electromagnetic radiations) and spread the light out into its component wavelengths. This allows us to measure individual wavelengths, and (ultimately) to determine which of these wavelengths are filtered by various

materials. This will be useful as a tool for comparing one sunscreen to another later in the module. To make effective use of your diffraction grating, you will need to build a spectroscope.

Spectroscope

A spectroscope is a device used for dispersing and viewing the component colors (wavelengths) of light. Collectively, the colors seen are called a spectrum. A simple but useful spectroscope can be constructed by using a diffraction grating, a shoe box, black paint, or paper and masking tape. An adaption to your spectroscope will later be made which will require some fluorescent paint and some tracing paper. Figure 1.4 will give you an idea of what your spectroscope will look like.

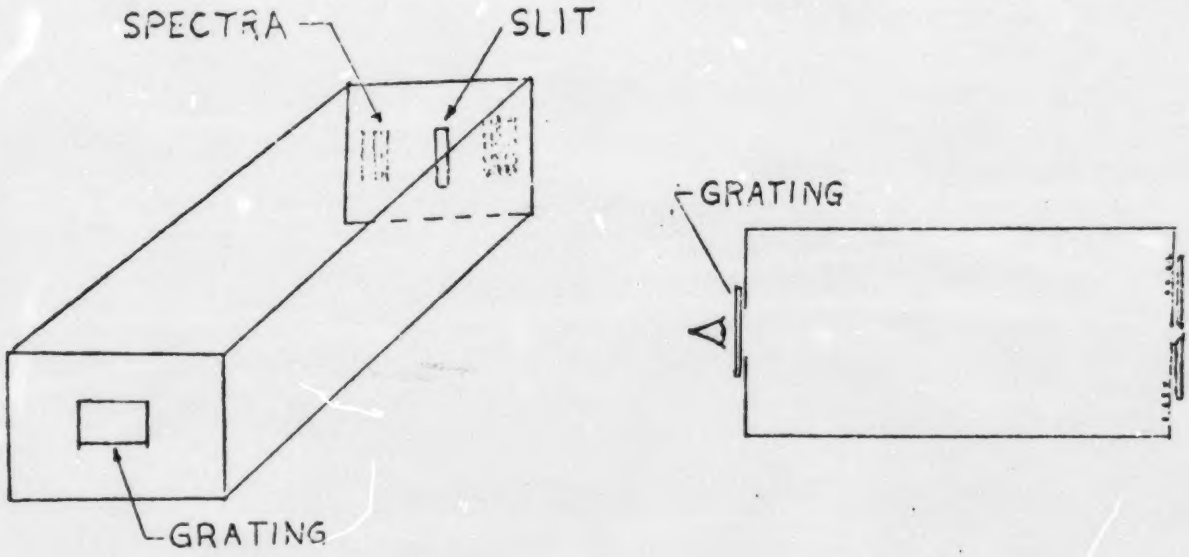


Figure 1.4

Sketch of Shoebox Spectroscope

Cut a 3cm square hole in one end of the box, and a vertical slit 3cm long and 1 cm wide in the other end. Use black paper to line the box and lid, or spray the inside with flat black paint. Using masking tape, carefully make a narrow slit over the vertical opening at the end of the box. Next, tape the grating over the square hole and look through the grating and slit toward a

line filament incandescent lamp which has a clear glass bulb. When the bulb, slit, grating, and eye are aligned you should be able to see a horizontal band of colors near the corners of the box on each side of the vertical slit. If you do not see the horizontal band of colors, rotate the grating 1/4 turn so that the microscopic lines on the grating are parallel to the slit.

The band of colors you see when viewing the hot filament of an incandescent lamp is the spectrum of colors radiated by the lamp. All objects that give off light can be viewed through your spectroscope, and each radiating object has a spectrum of colors characteristic of the object and its temperature.

Solar Spectrum

The sun is a source of white light, but do not look directly at the sun with your spectroscope! Since it is an intense source of light containing radiation, it is extremely dangerous to the eye.

As one possible solution to this problem, you could reflect sunlight into your spectroscope from a partially reflecting surface made from a piece of transparent material such as glass or plastic which has been backed with black paper. The black paper absorbs some of the sun's radiation. This suggestion is illustrated in Figure 1.5.

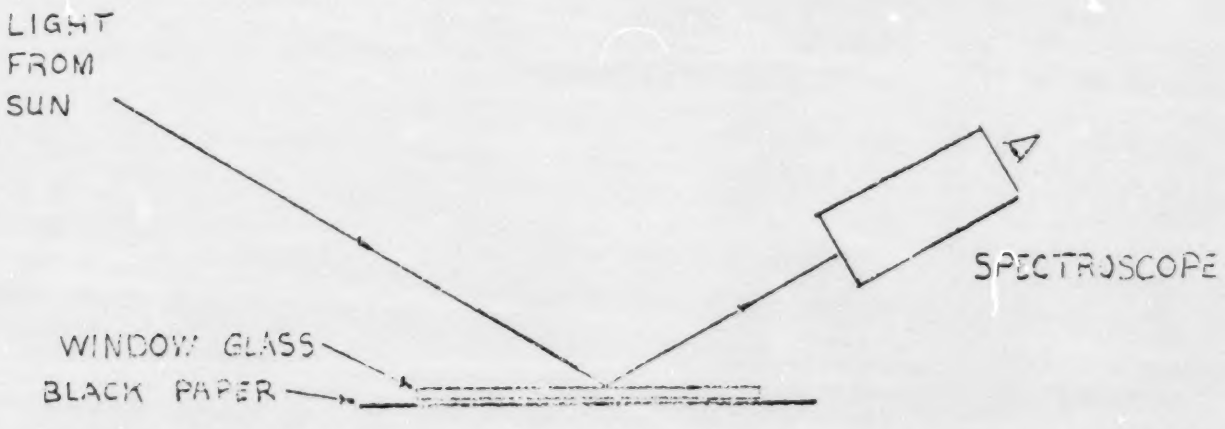


Figure 1.5

Arrangement for Safely Viewing Sunlight

Now that you have observed the spectrum of white light source and the sun, could there be other light given off by these sources that the human eye does not detect directly?

You are probably familiar with "black light" sources used to illuminate fluorescent posters. The name "black light" comes from the fact that it is light which the human eye does not detect, hence, since we do not see this light, a source of light which cannot be seen would appear to be dark or black. Most commercial "black light" sources contain some visible radiation. It is usually a very light violet color. Look at a "black light" source with your spectroscope. Since there are no other visible colors except violet if there is other radiation it must be at wavelengths shorter than violet. This type of radiation is referred to as ultraviolet.

Detecting Ultraviolet Light

Since our eye does not detect ultraviolet (U.V.) radiation, how can we determine its presence? Does the fluorescent poster give you a hint?

When ultraviolet light shines on certain compounds, those compounds seem to glow and give off bright colors of light. The process of a material absorbing light of short wavelength (U.V.) and emitting light of a longer wavelength (visible light) is called fluorescence, and the materials are said to be fluorescent. Hence, you could use a fluorescent material as a detector of U.V. radiation.

Modifying your spectroscope so that it becomes a U.V. spectroscope is somewhat tedious. However, it can be done, and the observation of U.V. light is rewarding. First you will need some fast drying fluorescent paint. The colors solar yellow or chartreuse work nicely.

The grating is taped inside the box just behind the slit. The screen, which is just smaller than one end of the box, is taped about 30 cm from the

viewing port. (This is the hole over which the grating is initially taped.) The screen is made of onionskin or tracing paper, and is lightly painted over the bottom half with the fluorescent paint. Use a piece of masking tape to make the border between the painted and unpainted area sharp.

Now, with the screen in place, if you look at a very bright source of light that contains both visible and UV light, you can see the spectrum of visible light on the unpainted portion of the screen and the UV on the painted portion. This is illustrated in Figure 1.6 for the case of a high intensity incandescent light source from a slide projector, with the lens removed.

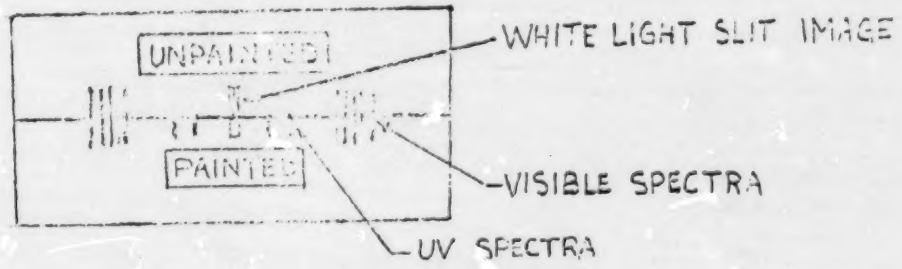


Figure 1.6

A better source of UV light is a high pressure mercury arc discharge tube. This produces the spectrum which is characteristic of mercury vapor, and has several lines in both the visible and UV region. The mercury arc discharge tube can be used later in testing sunscreens.

Now that you have discovered that the sun, as well as some other sources of light, emit ultraviolet radiation, you can use your spectroscope to measure some of the wavelengths which you have detected and then compare the spectrum of the sun to the spectrum of a laboratory source such as mercury vapor. The purpose of this comparison is to determine whether or not the mercury vapor light might be useful as a substitute for sunlight in a laboratory investigation of sunscreens.

Measuring the Wavelengths of Light

You can determine the wavelength of a spectral line by using the equation for a diffraction grating:

$$d \sin \theta = \lambda$$

A good explanation for this may be found in one of the references listed at the end of this section[1,2,3].

The spacing of the grooves in the grating is represented by d, and θ is the angle formed between the white light slit image (see Fig. 1.6) and the spectral line of which you wish to determine the wavelength. Accurately measuring the angle θ can be a problem. The angle can be determined with reasonable accuracy in radians by taking the ratio of x to D as shown in Fig. 1.7. The distance from the middle of the white light slit image to the spectral line is x. It may be measured by placing a scale along the bottom edge of the screen and illuminating it with a small flashlight bulb. This bulb can be powered by a battery outside the box with the connecting wires being passed through two small holes in the box and soldered on to the bulb. Since the light from the bulb may be brighter than the spectrum, it should be turned on only momentarily to read the scale. The distance from the slit to the screen is D and may be directly measured by removing the lid of the box.

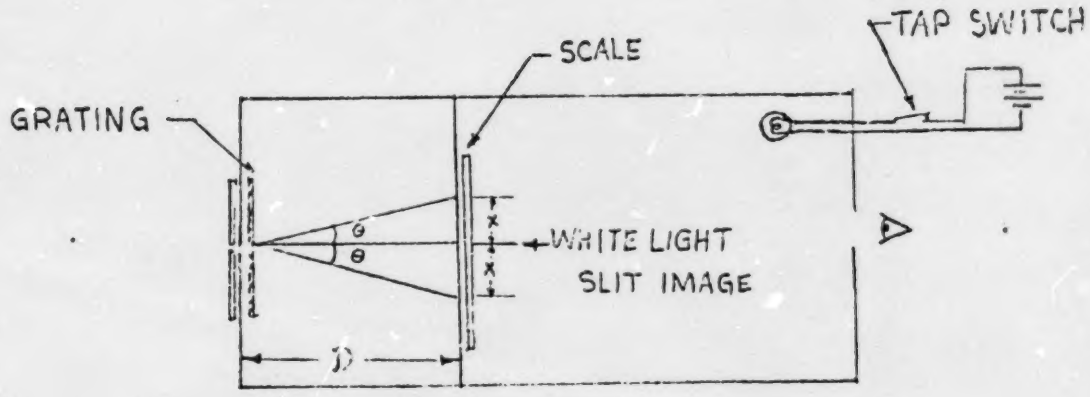


Figure 1.7

Modified Spectroscope for UV Observation

and Wavelength Measurement

The remaining value to be determined is d, the spacing between the grooves. To obtain this value, you will need to know the number of grooves per unit of distance in the grating. This information is generally provided by the manufacturer. A typical grating (from Edmund Scientific) has 13,400 grooves per inch. The spacing between the grooves is the inverse of this number, or, 7.46×10^{-5} inch. In the metric system this becomes 1.90×10^{-4} cm or 1900nm. The nm stands for nanometer which is equal to 10^{-9} m. The nm is a convenient unit to use for wavelengths of light and other small quantities and will often be used in the rest of this module.

Sample Problem:

Find the wavelength of a spectral line from the spectroscope variables

Distance from white line image to spectral line (x) = 2.5cm

Distance from slit to screen (D) = 15 cm

Distance between grooves (d) = 1.9×10^3nm

$$\theta = \frac{x}{D} = \frac{2.5\text{cm}}{15\text{cm}} = .17 \text{ radians } (9.5^\circ)$$

$$\lambda = d \sin \theta = (1.9 \times 10^3\text{nm}) (\sin .17 \text{ radians})$$

$$= 3.2 \times 10^2\text{nm}$$

Questions - Segment I

1. Yellow light travels through a vacuum at a speed of 3×10^8 m/s and has a wavelength of 6×10^{-7} m. What is the frequency of yellow light?

2. From the previous problem, what is the wavelength of yellow light in nanometer units?

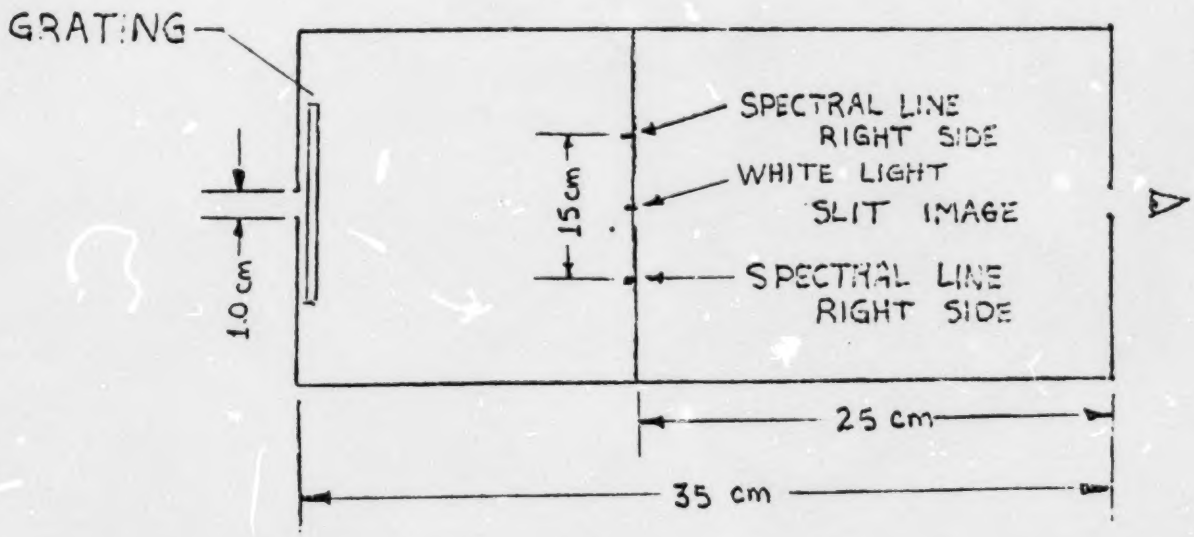
3. Light shining through a picket fence is not observed to diffract but rather casts sharp shadows. Is this a violation of the wave properties of light? Through what sort of a "picket fence" would you observe light diffracting?

4. Look at a mercury vapor bulb through your spectroscope. You should observe a distinct green line. Using the wavelength formula from this segment, find the necessary unknown values and calculate the wavelength of this green line.

5. Look at a flourescent light tube with your spectroscope. You should see a continuous horizontal band of colors along with bright vertical bands of several colors superimposed upon the continuous spectrum. Why do you see both the continuous spectrum and superimposed bright lines? How do the colors of these bright lines compare with those colors observed when looking at the mercury vapor light?

Here is a brief explanation: The continuous spectrum is characteristic of the white light being emitted by the flourescent material on the tube. The bright lines appear because the tube contains mercury vapor, which, due to its atomic structure and high voltage used to light the tube, gives off just these certain wavelengths. These bright lines, called emission lines, are emitted by a wide variety of substances. The colors of each substance's emission lines are unique to that particular substance. This provides a convenient and often-used method for identifying unknown substances. Since both the mercury vapor light and the flourescent tube contain mercury vapor inside, then they have the same set of emission lines.

6. Below is a diagram of your modified (UV) spectroscope. Various dimensions have been put in. Using these dimensions, do whatever calculation is necessary to find the wavelength by the corresponding pair of spectral lines pictured. Assume that the scratches in the diffraction grating are spaced 1.90×10^{-4} cm apart.



Is the wavelength you found visible or UV?

7. It was stated earlier in this segment that waves transport energy. Give some evidence to support this fact. Your evidence could relate to either mechanical waves or electromagnetic waves.

References - Segment I

1. The Project Physics Course, Holt, Rinehart and Winston, Inc., New York, Toronto.

2. P.S.S.C. Physics, D. C. Heath and Company, Boston.

3. Rogers, Eric, M., Physics for the Inquiring Mind, Princeton University Press, Princeton, New Jersey, 1960.

Segment II

THE EARTH'S ATMOSPHERE AS A FILTER OF SOLAR RADIATION

The principal method of energy transfer from the sun to earth is by radiation - the propagation of electromagnetic waves as discussed in the previous segment. After this radiant energy has traveled through the vacuum (space) that separates the earth from the sun, it then propagates through the earth's atmosphere. As the radiant energy passes through the atmosphere, some of it is filtered by either reflection or absorption, so what finally reaches the earth at mean sea level is less intense than in the upper atmosphere. The process of filtering by absorption is the topic to be discussed in this segment.

The way radiation interacts with the atmosphere depends upon its wavelength and intensity of radiant energy. The relationship between intensity and wavelength for solar radiation is shown in the graph in Fig. 2.1. The figure is actually the superposition of two graphs. One graph shows the intensity of solar radiation, as a function of wavelength, just outside the earth's atmosphere, while the other shows the intensity of that radiation (again as a function of wavelength) which reaches the earth at mean sea level. Intensity of the radiation is plotted on the vertical axis in units of watts per square meter for each wavelength, and the wavelength is plotted along the horizontal axis in units of nanometers ($1nm = 10^{-9}m$).

Notice that both curves have a maximum intensity at a wavelength of about 450nm. Outside the earth's atmosphere the intensity is about 2.3 watts per square meter for this wavelength, whereas it is down to 1.5 watts per square meter at mean sea level. This corresponds to a decrease of about 35% in intensity of the radiation coming through the earth's atmosphere at this particular wavelength. At other wavelengths the decrease in intensity is almost 100%, and in general the overall radiant energy is lower at sea level than at the outer atmosphere for all wavelengths.

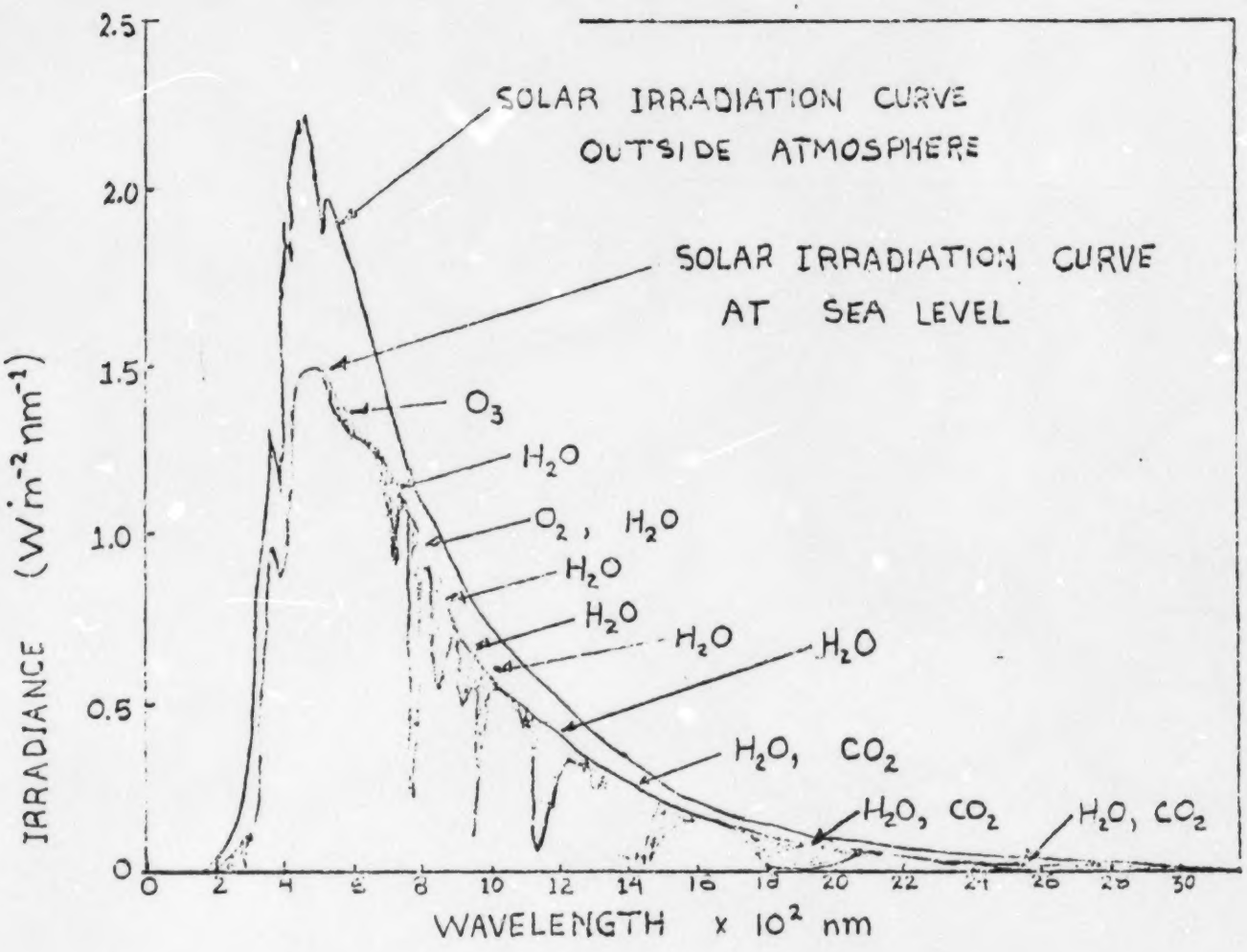


Figure 2.1 The spectrum of solar radiation at the outer edge of our atmosphere and at sea level showing the absorption of various wavelengths by atmospheric gases. The intensity of radiation is given along the vertical axis in units of watts per square meter per nanometer and the wavelength in nanometers (1nm = 10^{-9}m) along the horizontal axis. After - Handbook of Geophysics and Space Enviroment.

The atmosphere contains a variety of elements and compounds with which electromagnetic radiation can interact to play an important role in the filtering process. Below is a list of the significant constituents in the atmosphere and their respective percentages.

Name	Symbol	Percent Abundance
Nitrogen	N_2	78.084
Oxygen	O_2	20.946
Argon	Ar	9.34×10^{-1}
Carbon dioxide	CO_2	3.1×10^{-2}
Neon	Ne	1.82×10^{-3}
Helium	He	5.24×10^{-4}
Methane	CH_4	1.5×10^{-4}
Kripton	Kr	1.14×10^{-4}
Hydrogen	H_2	5×10^{-5}
Nitrous oxide	N_2O	3×10^{-5}
Xenon	Xe	8.7×10^{-6}
Carbon Monoxide	CO	1×10^{-5}
Ozone	O_3	(Variable) up to 10^{-5}
Water	H_2O	(Variable) up to 1

Table 2.1 Gases which make up the earth's atmosphere, and the percentage abundance of each gas.

Of the constituents listed above, the ones which significantly absorb solar radiation are ozone, oxygen, water, and carbon dioxide. These compounds absorb radiation best at the particular wavelength illustrated in Fig. 2.1.

The interaction of radiation with atoms and molecules is best understood with a knowledge of what is known as the quantum theory of radiation, which is beyond the level and scope of this module. The significant information, as far as this module is concerned, is that the amount of energy

in electromagnetic radiation is inversely proportional to the wavelength of that radiation. Long wavelength (low frequency) waves have little energy, whereas, short wavelengths (high frequency) waves are very energetic.

Radiant energy is absorbed by molecules in the atmosphere by a variety of ways depending upon the energy of the incoming radiation. Lower energy radiation (that with longer wavelengths), upon interacting with a molecule may cause the molecule to have internal motion (rotate or vibrate), but the energy is not sufficient to cause chemical changes. If the energy is somewhat higher (shorter wavelengths), it can overcome the binding forces which hold the molecule together. In this event the molecule separates into two or more particles. This separation process is referred to as photodissociation. At still higher energies (extremely short wavelengths), the radiation can affect the electronic structure of atoms. When the radiation causes an electron to be ejected from an atom or molecule, the process is known as photoionization. Both photodissociation and photoionization involve multiple reactions. At different atmosphere altitudes, different reactions are more or less prevalent. It is not our intent to thoroughly explore these variables in this paper, but rather to give just an example of each of these two processes and to stress their importance. If the reader wishes to further research the function of the earth's atmosphere and the photochemical reactions which occur in it, there is a partial list of references at the end of this section which may be helpful.

PHOTOIONIZATION

This filtering process is extremely important to our existence on earth as it results in energy absorption of radiation having wavelengths less than 100nm. Radiation of this frequency in the extreme ultraviolet range

would be very destructive on earth if unfiltered. A typical photoionization proceeds as follows:

$$O \xrightarrow[\text{Peak 70nm}]{\text{UV radiation}} O^+ + e^-$$

The radiation has caused the oxygen to ionize. This ionized oxygen cannot recombine with the electron without an intermediate process like the following:

$$O^+ + O_2 \rightarrow O_2^+ + O$$

or $$O^+ + N_2 \rightarrow NO^+ + N$$

These molecular ions are now able to combine with an electron to once again become neutral.

$$O_2^+ + e^- \rightarrow O + O$$

or $$NO^+ + e^- \rightarrow N + O$$

Notice what has happened to the radiant energy. It started out being used to ionize an atom of oxygen which was unstable and therefore reacted with either O_2 or N_2. These now have an excess of energy which will ultimately be used to dissociate them into atoms of O or N. Once this occurs, these atoms can react with other radiation to continue the chain.

PHOTODISSOCIATION

There are two molecules which are primarily involved in photodissociation. As with photoionization, these reactions are vital to living organisms on earth.

For wavelengths between about 100-200nm, molecular oxygen, O_2, plays a significant role. The dissociation occurs as follows:

$$O_2 \xrightarrow[\text{Peak 150 nm}]{\text{UVC Radiation}} O + O$$

Recombination into the diatomic molecule O_2 can be done if another atmospheric molecule is available to absorb the excess energy from this recombination of the two oxygen atoms. This reaction can be represented in the following manner:

$$O + O + M \rightarrow O_2 + M$$

where M represents any other atmospheric molecule such as N_2, CO_2, etc. Without the added molecule, there would be only a short lived O_2 molecule which would rapidly redissociate:

$$O + O \rightarrow O_2 \rightarrow O + O$$

The other molecule actively involved in photodissociation is Ozone, O_3. The role of O_3 as a filter in the atmosphere cannot be overemphasized as it accounts for the filtering of the near UV radiations between 200 and 300nm. Radiations at these wavelengths are emitted in abundance from the sun, and without Ozone to filter, there would be severe damage done to all forms of earthly life. The photodissociation of Ozone is as follows:

$$O_3 \xrightarrow[\text{Peak 260 nm}]{\text{UVC Radiation}} O_2 + O$$

The recombination of O_2 and O back into O_3 must occur with the help of another atmospheric molecule as seen earlier:

$$O_2 + O + M \rightarrow O_3 + M$$

Again M represents some atmospheric molecule, and without this molecule to absorb the excess energy of O_2 and O recombining, the reaction would reverse immediately:

$$O_2 + O \rightarrow O_3 \rightarrow O_2 + O$$

The formation of O_3 after it dissociates is of great importance. Without O_3 being reformed, there would be an imbalance in the atmosphere and the Ozone would soon be depleted. Its presence is essential for the filtering of photons in the 200nm and 300nm range. The ozone in the upper atmosphere can be thought of as an "umbrella" which protects and makes life on earth possible. The need for this "umbrella" is the reason scientists are so concerned with the release of fluorocarbon compounds (Freon, chlorofluoromethane) in the atmosphere.

Freons (chlorofluoromethanes) are used as refrigerants and as propellants in aerosol spray products. After they are released from the spray cans, they float up into the upper atmosphere and photochemically interact with the ozone to effectively remove the ozone "umbrella" from the upper atmosphere. The extent of the possible hazards of chlorofluoromethanes in the upper atmosphere has not been fully determined, and is in itself an issue of current societal concern. For further information on the ozone layer and the hazards of Freon in the atmosphere, the reader can consult references 3 and 4 at the end of this segment.

Figure 2.2 summarizes the process by which various wavelengths are filtered by the unpolluted atmospheric air, and shows at what approximate altitude the filtering occurs. The absorbing molecules are listed below the curve to illustrate at which altitudes and at which wavelengths they play a role.

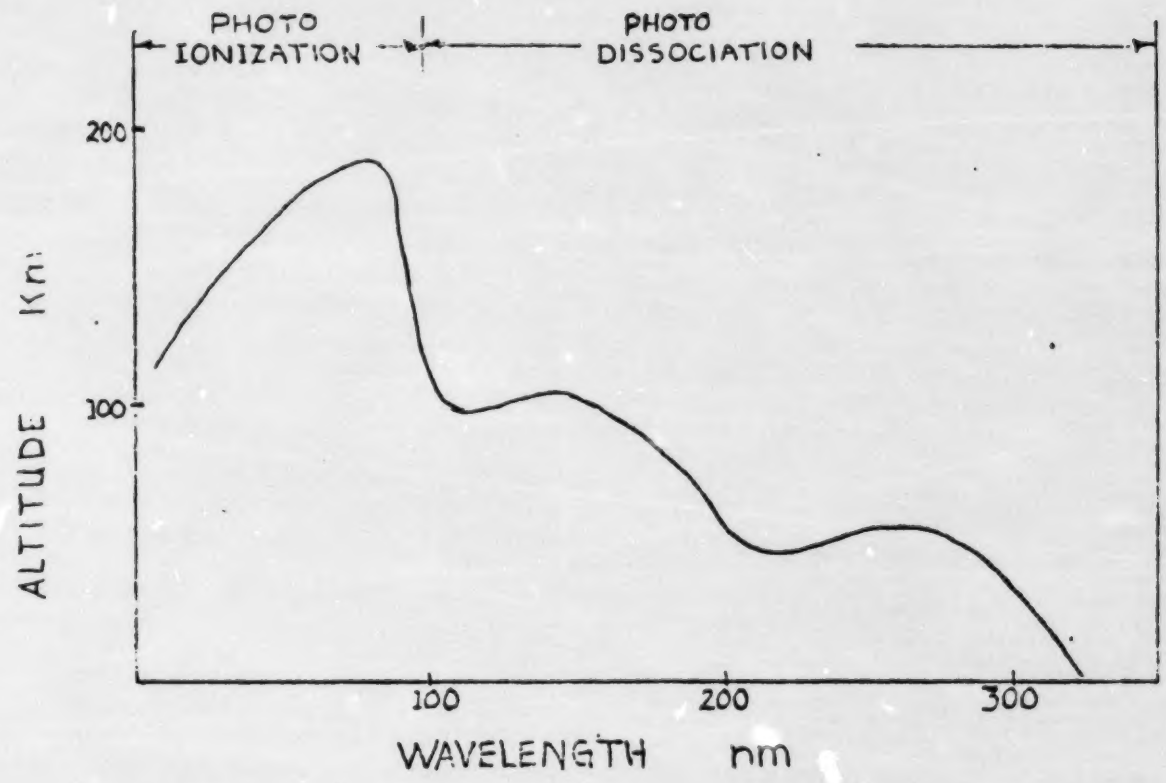


Figure 2.2 Diagramatic representation of the ultraviolet absorption bands of nitrogen, oxygen, and ozone. After R. M. Goody and C. G. Walker, Atmospheres, Prentice Hall.

Now that some of the absorption processes have been discussed, we should take a brief look at what is not absorbed by the atmosphere and then what damage might be done to the skin if not adequately protected. Of the wavelengths emitted by the sun, those below about 390nm are in the ultraviolet range. This range can be divided into three subranges referred to as UVA, UVB and UVC.

UVA radiation is from 390nm to 320nm. This radiation is not significantly filtered by the atmosphere and is not significantly damaging to the skin.

UVB radiation is from 320nm to 286nm. This radiation has been found to be by far the most dangerous to the skin. A significant amount of this radiation gets through the earth's atmosphere and can cause a great deal of damage to all forms of life. Typically the skin can withstand 100 to 1000 times more UVA radiation than UVB.

UVC radiation covers wavelengths from 286nm down to 40nm. These wavelengths are effectively absorbed by the atmosphere and rarely pose a problem to life on earth.

Keeping this in mind, our attention should now turn to two major questions:

(1) What harm is caused to our skin by UVB radiation?

(2) What can be done to help prevent damage to the skin caused by this radiation?

These questions are the major topics of the two sections which follow.

Questions - Segment II

1. What compounds in the atmosphere are principally responsible for absorbing the sun's radiation?
2. Discuss the difference between photoionization and photodissociation.
3. What constituent of the atmosphere is responsible for absorbing (by photodissociation) the solar energy in 200 to 300nm range?
4. Of the three subranges of UV, which one poses the greatest threat to life on earth? What wavelengths does it cover?
5. In Fig. 2.1, the radiant energy entering the earth's atmosphere is greater than that reaching the earth's surface. Considering the conservation of energy, what happens to this decrease in energy?
6. On page 25 it is stated that ionized oxygen cannot recombine with an electron without an intermediate process. Can you give any explanation of this?

For Further Study:

The graph in Fig. 2.1 can be more thoroughly examined. Try the following:

1. Roughly determine the area under the graph. Do this by appproximating the graph as a triangle, and then multiplying (1/2 x base x height). The value obtained will have units of watts/m^2. This will therefore indicate the quantity of solar energy available on the earth's surface. The value you obtain should be approximately 1 kw/m^2. Despite this rather large magnitude, we cannot depend upon the sun for all of our energy needs. Discuss some of the reasons why.
2. The sun's radiation spectrum is approximately the same as the spectrum emitted by a black body at 5900°K. Could this imply what the sun's average temperature might be? Look up the reference given with the graph for a plot of the 5900°K black body radiation.

3. For more information on atmospheric filtering, particularly the relationship between altitude and filtering, look up the Chapman Profile in reference 2.

4. The ozone layer, so vital to our existence on earth, turns out to be surprisingly thin. At one atmosphere of pressure, it would average only 1cm thick. This thickness varies from place to place and from season to season. Where do you think it is the thickest? Where is it thinnest? See if you can find more information on this valuable atmospheric constituent.

Segment II - References

1. Handbook of Geophysics and Space Environment.

2. Goody, R. M. and C. G. Walker, "Atmospheres", Prentice Hall, Englewood Cliffs, N.J., 1972.

3. Woofsy, S. C., McElroy, M. B. and Sze, N. D., "Freon Consumption: Implications for Atmospheric Ozone", Science 187, pp. 535-537, 1975.

4. Giese, A. C., Living with Our Sun's Ultraviolet Rays, Plenum Press, pp. 170-179, 1976.

Other References

McEwan and Phillips, "Chemistry of the Atmosphere," John Wiley & Sons, New York, 1975.

Hidore, John J., "A Geography of the Atmosphere," W. C. Brown Co., Dubuque, Iowa, 1969.

Segment III

SKIN, DAMAGE CAUSED BY SOLAR RADIATION, AND SUNSCREENS

Although a significant majority of the sun's harmful rays are filtered by the atmosphere as explained in the previous section, there is a narrow band of unfiltered wavelengths in the UV range which can do a great deal of damage to the skin. The damaging wavelengths are in the UVB range from 286 to 320nm. Generally, wavelengths shorter than this are filtered completely by the ozone. Wavelengths greater than this produce some short lived tan and are not signficantly harmful to the skin.

SKIN

To better understand the process by which burning and other skin damage occurs, it is necessary to briefly examine the anatomy of human skin.

The skin is composed of two layers called the epidermis and dermis. The epidermis is the outer layer and serves as a protection to the body from the environment. The dermis, which lies below the epidermis, is far thicker than the epidermis and provides the nourishment for the cells in the epidermis as well as provides for several other vital functions, to be discussed later.

Epidermis

This layer is subdivided into several sub-layers. The outermost layer is composed of horny cells which no longer possess the essential properties of life. These cells are continuously being shed and replaced by cells which are produced in the deeper layers. The production of new cells which eventually replace those which are shed, occurs in the basal layer of the epidermis (see Fig. 3.1). These new cells push upwards through the prickle cell layer and granular layer before reaching the horny layer. As these cells move further from the basal layer, they gradually lose the nourishment available from the blood cells in the dermis and therefore die. The basal cell layer contains

special cells known as melanocytes which produce a substance called melanin, a dark pigment which helps determine skin color. The epidermis, which makes up only about 20% of the total skin thickness, is extremely vital in the protection it affords to the dermis. It shields the dermis from damage which would result from contact with environmental bacteria, chemicals, and some electromagnetic radiations.

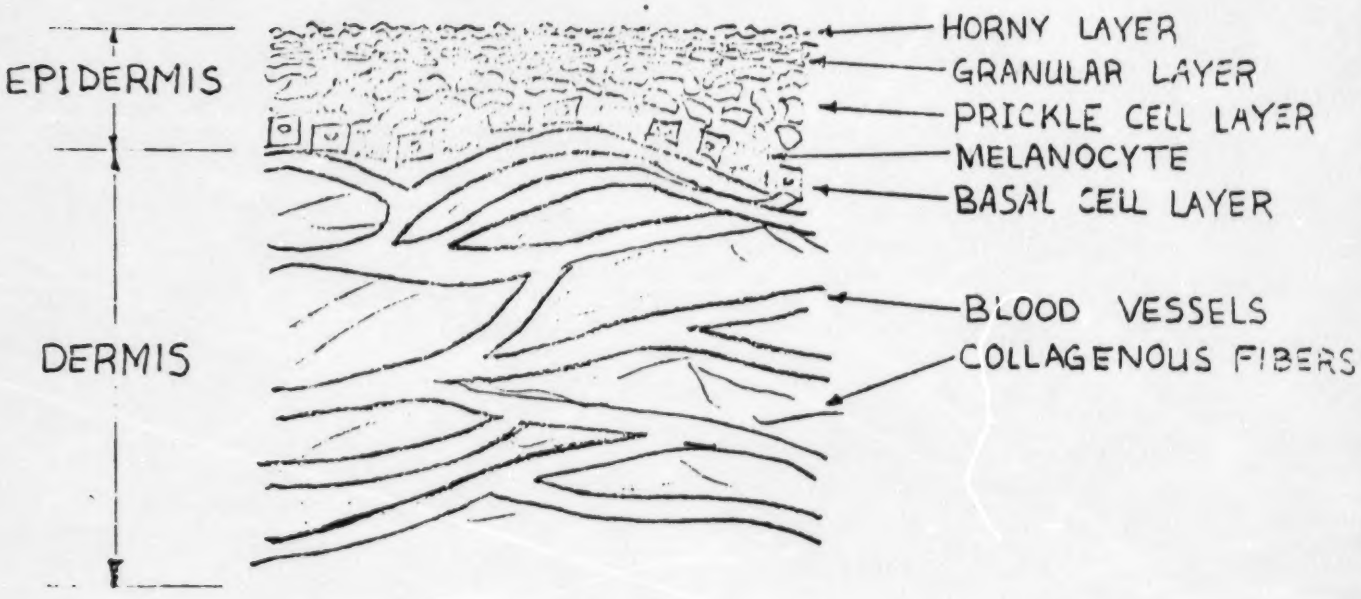


Fig. 3.1

Cross Section of Human Skin

Dermis

The dermis, sometimes called the true skin, varies in thickness from about 0.5mm to 6mm and contains a great deal of fibrous, elastic connecting tissue which accounts for the skin's toughness. It also contains fats, numerous blood vessels, nerves, sensory receptors, hair follicles, sebaceous glands and sweat glands. These provide the necessary nourishment for cell production in the epidermis, as well as provide for lubrication, secretion of waste, and temperature control of the body.

SUNBURN

Sunburn is characterized by a reddening of the skin (erythema) accompanied by pain, and generally is noticed beginning from four to fourteen hours after exposure. (Although this time can be as long as three days.) Sunburn is often measured in a unit referred to as the minimal erythemal dose (MED) which varies from individual to individual, and is defined as the amount of energy needed to produce minimal perceptable redness for that individual. In direct sunlight, the MED may be as little as ten minutes for those with very light skin and as long as several hours for persons of dark pigmentation. For a particular light source such as the sun, mercury, or Zenon arc lamp, the MED refers to the time required for a minimum perceptable erythema (the Greek word for flushing). From this definition of the MED, it must be realized that it is a subjective unit of measure.

One MED generally kills some of the cells in the prickle cell layer of the epidermis and causes a slight enlargement of blood vessels in the dermis. A dose of five to ten MED will cause some tissue fluid and white blood cells

to collect between the epidermis and dermis resulting in a blister. Later, fluid is re-absorbed and the cells in the epidermis above the dead prickle cells are shed in scales or are peeled off in a layer. New cells develop rapidly and a new epidermis replaces the old. Provided that the old epidermis was not significantly damaged, the new epidermis will be much like the original.

LONG TERM EFFECTS

The real danger in over-exposure is not in the erythema which commonly accompanies it, not in the formation of blisters as in the more severe cases, but rather in the long term damaging effect on the skin. Skin which has been excessively exposed to solar radiation for many years appears flabby, dry, deeply wrinkled, and prematurely aged. The sebaceous glands which normally provide lubrication to the skin, keeping it soft and pliable, secrete less of the lubricating substance called sebum. The poorly lubricated skin dries, loses its pliability and its ability to stretch and shrink back to normal. This results in wrinkling of the skin which is characteristic of long term over-exposure.

The effects just mentioned are observed in all people who have been excessively exposed to the sun. Besides this mostly cosmetic damage, persons whose skin has been severely sun damaged run a far greater risk of developing skin cancers. There is an exceptionally high frequency of skin cancer in people such as construction workers and farmers whose jobs require long hours in the sun. From observations by physicians and dermatologists it has been established that there is a direct relationship between the frequency of skin cancer and the amount of exposure to solar radiation.

A study done by Auerbach[1] shows an inverse proportionality between incidences of skin cancer and degrees of latitude in the Northern Hemisphere. On data taken in various cities throughout North America, a plot of rate of incidence of skin cancer vs. latitude degrees shows a doubling of skin cancer for every 3°48' reduction in latitude (approximately 265 miles).

Table 3.1 shows a chart compiled by Sanderson[2] which points out the rate of skin cancer for white and non-white males and females in both the north and the south and on what part of the body the cancer was found.

	MALE		FEMALE	
Skin Color and Region	Face, head and neck	Other sites	Face, Head and neck	Other sites
White				
North[a]	26.8	6.6	20.5	4.9
South	120.6	22.7	72.2	15.8
Non-white				
South[b]	2.5	2.9	4.2	4.3

a North samples were from Chicago, Detroit, Philadelphia, and Pittsburgh. South samples were from Atlanta, Birmingham, New Orleans, and Dallas.
b Figures for the non-white population were similar but smaller.

Incidences of Epidermal Cancer Per 100,000

Table 3.1

From this data it is inferred that the darker the skin pigmentation, the less likely one is to have skin cancer from over-exposure to solar radiation. This point has been well documented in studies done by Kligman[3].

Further evidence implicating solar radiation as contributing to skin cancer can be readily seen in a survey mentioned by Giese[4] where 840 cases of basal cell carcinoma (a common form of skin cancer) were studied. In this sample, half of the carcinomia were found on the left side of the body and

half on the right as might be expected; but 91.2% were found on the head and neck with the remaining 8.8% on the rest of the body. Many more carcinomas (12 to 1) were found on the ears of men than on women, and more carcinomas were found on the lower legs of women than men. Research shows that on the upper part of the nose on the area near the lower eyelids, there are many more incidences of cancer than on areas of the face less open to the sun. Again, this evidence rather strongly suggests that exposure to the sun has a dramatic effect upon the likelihood of developing skin cancer.

PREVENTION OF DAMAGE

Nature itself provides the skin with a built-in, but inadequate, protection from the sun. As UV light strikes the skin, the melanocytes located in the basal layer of the epidermis generate more melanin and oxidizes the melanin already in the epidermis. Melanin is a pigment which determines skin color. As more melanin is produced and oxidized, it causes skin to darken, which somewhat protects it against further damage. To a lesser extent, the solar radiation also causes a slight but short lived increase in the thickness of the epidermis which also helps block further radiation. These naturally occurring protections are of limited value to people who spend long hours in the sun. Further protection through the use of sunscreens is necessary.

SUNSCREENS

The term sunscreen, as used in this module, is defined as any substance that shields and protects (partically or fully) human skin from the damaging effects of UVB radiation. Sunscreens should not be confused with suntan

lotions. The latter are products marketed as an aid to tanning. Some suntan lotion manufacturers claim to add a sunscreen to their product.

Sunscreens can protect the skin either physically or chemically. A physical sunscreen provides an actual barrier to sunlight. Clothing and beach umbrellas would therefore be physical sunscreens. There are also substances which can be rubbed on the skin which physically block sunlight. Examples of such materials are titanium dioxide and zinc oxide paste. Both of these compounds scatter and reflect incident UV light.

An ideal sunscreen would have the following properties:

1. it would block, by either absorption or reflection, all UVB radiation which damages the skin;
2. it could be topically applied to the skin when needed, and washed off when the need for it no longer exists;
3. in itself, it would not be damaging or harmful to the skin;
4. it would not be offensive in odor or appearance to the user.

Several cosmetic and pharmaceutical firms are presently manufacturing and marketing chemical sunscreens which have some of the above properties.

Chemical sunscreens actually absorb certain wavelengths of electromagnetic radiation. As this energy is absorbed by the sunscreen, several changes can occur in the absorbing compound[6,8].

a) Light energy is converted into heat.

b) The sunscreen's molecules can dissociate into atoms or radicals.

c) The molecule can be excited to higher energy levels and its energy transferred through collision with another molecule, followed by a chemical reaction.

d) The compound can become excited and lose its energy immediately by flourescence or, at a later time by phosphorescence.

A common and convenient way of categorizing a sunscreen's effectiveness

(efficacy) is by what is known as a "protection factor" (PF)[4,5]. The PF is a unitless quantity defined as the ratio of the minimum dose of sunlight needed to produce erythema on sunscreen protected skin to that dose producing the same effect on unprotected skin,

$$PF = \frac{\text{time of one MED for sunscreen protected skin}}{\text{time of one MED for unprotected skin}}$$

(using a standardized thickness of sunscreen for the protected skin). The PF of a sunscreen is a factor that accounts for all the variables (UV absorption range, maximum absorbance, molar absorbivity, concentration, pH, solvent) that determine a sunscreen product's effectiveness.

PF's are integers which are conspicuously displayed on the product's container. For example, if the number is "5" (meaning a PF of 5) then you can stay out in the sunlight 5 times longer when using this product to obtain the same dose of UVB as you would get without using the product.

On data in Table 3.2 taken on a wide variety of sunscreens[7], the protection factors varied from an average of about 3 to about 18.

Sunscreen	Protection Factor Mean MED's	Range MED's	Number of Subjects
Pabonal (5% amino benzoic acid)	17.6	10-21	23
Presun (5% amino benzoic acid)	17.6	10-21	23
Maxifil (4% cinoxate, 5% methyl anthranilate)	9.6	6-14	23
Sea & Ski (glyceral p-amino-benzoate)	8.3	5-11	13
RVPaque (red petrolatum, zinc oxide cinoxate	7.7	6-9	13
Solbar (3% oxybenzone, 3% dioxybenzone)	6.7	5-10	23
Sunswept (3.5% digalloyl trioleate)	6.6	5-9	23
Estee Lauder UV Screening Lotion (padimate)	6.6	5-8	16
UVAL (19% sulisobenzone)	6.6	6-9	16
Afil Cream (5% titanium dioxide, 5% meth-1 anthranilate)	6.3	6-8	16
Coppertone (homosalate)	6.0	4-7	17
Pan Ultra (diphenyketone)	6.0	4-7	17
Pabafilm (padimate)	5.9	4-9	23
Sungard (10% sulisobenzone)	5.9	3-8	17
Sundare (cinoxate)	5.9	5-7	17
Black Out (padimate)	5.5	4-7	17
RVP (red petrolatum)	3.2	2-4	18

Table 3.2

Sunscreen Protection Factor at 305nm

The PF's in Table 3.2 were obtained with an application of $30\mu l/cm^2$ for each of the sunscreens tested.

STUDENT INVESTIGATION

In the following section a method is outlined in which the student might do his own investigation of the effectiveness of locally available sunscreens. In preparation for this, students should obtain several different brands of sunscreens which contain a variety of active ingredients. These could be tested at various wavelengths in the UV range to determine relative effectiveness. The student may be interested in comparing his findings to those mentioned in Table 3.2.

COMPARISON PROJECT

If you are unable to do the lab in the next section, the following project might be substituted.

In a report done in 1978 by a panel appointed by the FDA, 21 ingredients were studied and given approval as being safe and effective as sunscreens. The panel also listed three ingredients, then in use, as "not generally recognized as safe and effective" as sunscreens. These are listed in Table 3.3. As an alternative to actually testing the effectiveness of commercially available sunscreens in the lab, you might read the labels of sunscreens and determine which are acceptable and which are not according to the FDA report. While checking the ingredients of these sunscreens, you might also refer to Table 3.2 to see if any of the ingredients listed in Table 3.3 are found in products listed here. You should be able to draw a conclusion as to which are the most desirable sunscreens based upon the PF and FDA report.

Safe and Effective Sunscreens

Amino Benzoic acid, also called Paraamino Benzoic acid

Cinoxate

Diethanolamine p-methoxycinnamate

Digalloyl trioleate

Dioxybenzone

Ethyl 4-(hydroxpropyl) aminobenzoate

2-Ethylhexl 2-Ciano 3,3-Diphenylacrylate

Ethylhexyl p-methoxycinnamate

2-Ethylhexyl salicylate

Glyceryl aminobenzoate

Homosalate

Lawsone with Dihydroxyacetone

Methyl anthranilate

Oxybenzone

Padimate A

Padimate O

2-Phenylbenzimidazole-5-sulfonic acid

Red Petrolatum

Sulisodenzone

Titanium dioxide

Triethanolamine salicylate

Not Safe and Effective

2-Ethylhexyl 4-phenylbenzophoenone-2 carboxylic acid

3-(4-methylbenzylidene)-camphor

Sodium 3-4-dimethylphenyl-glyoxylate

Table 3.3
Food and Drug Administration Report

Questions - Segment III

1. What effect does one MED have on the skin?

2. One MED is not a fixed period of time, but varies according to many circumstances. List some factors which would influence the duration of one MED.

3. Where in the skin does cell production occur to replace lost cells?

4. How do melanocytes serve to help protect the skin from further sun damage?

5. What is melanin?

6. Cite some evidence that skin cancer is directly related to solar radiation.

7. What is meant by a Protection Factor of 8?

8. If the MED for a person at around noon were one-half hour, how long would the MED become if the sunscreen applied offered a PF of 12?

9. In early summer John Roe's unprotected skin can withstand a twenty minute exposure to noon-day sun before any signs of reddening appear; on the other hand, Mary Doe's unprotected skin can only withstand a five-minute exposure under similar conditions. How does one MED for John compare to that for Mary?

10. Residents of south-western Texas are advised to stay out of the direct sunlight between the hours of 10:00 A.M. and 4:00 P.M. during the summer months, whereas no such advice is, in general, given to the residents of the state of New York. Why would this be the case?

Segment III References

1. Auerbach, H., Publ. Health Rep., No. 76, Washington, D. C. 1961, p. 345.
2. Sanderson, "Comparative Physiology and Pathology of the Skin", A. J. Rook and G. S. Walton, Eds., Davis, Philadelphia, Pa., 1965.
3. Kligman, A., Sunlight and Man, edited by T. B. Fitzpatrick, et. al., Tokyo University Press, Tokyo, pp. 159-160, 1974.
4. Giese, A., "Living With Our Sun's Untraviolet Radiation", Plenum Press, New York and London.
5. Amer. Hospital Formulary Ser., (84:80), Edited by Kepler, July 1978.
6. Johnson, Handbook of Non-Prescription Drugs, Chapter 25, 1977.
7. Cripps, D. J. and S. Hegedus, Arch. Dermatel. 109, 202, 1974.
8. Daniels, F. and R. A. Alberty, "Physical Chemistry" 2nd Ed., Wiley, New York, 1961, p. 654.
9. Summary Minutes of Meetings 1-16, OTC Panel Tropical Analgesic, Antiheumantic, Otic, Burn, Sunburn Treatment and Prevention Drugs, Division of OTC Drug Evaluation, Bureau of Drugs, Dept. of Health, Education and Welfare, Rockville, Maryland, Mar. 1973 - Jan. 1975.
10. Sayre, R. M., et al., Archives of Dermatology, 114, 1649, 1978.
11. Sayre, R. M., et al., Photochemistry and Photobiology, 29, 559, 1979.
12. Sayre, R. M., et al., Archives of Dermatology, 115, 46, 1979.
13. Federal Register 43, No. 166, 38206-38269, August 25, 1978. (Methods and procedures of determining the efficacy of sunscreen ingredients published by the Federal Food and Drug Administration.)

SEGMENT IV

LABORATORY PROJECT: RELATIVE EFFECTIVENESS OF COMMERCIALLY AVAILABLE SUNSCREENS

Introduction

There are two common methods of comparing the effectiveness of sunscreens (see reference 10 of Segment 3); they are called *in vivo* and *in vitro* testing. *In vivo* testing means performing the test at the site for which the materials being tested were designed to be used. For sunscreen, *in vivo* test means using human subjects and testing the products on living human skin. (The FDA imposes stringent regulations on tests involving human subjects so that their human rights will not be violated.) *In vitro* testing means to test in an artificial environment, or at a site for which the product would not normally be used but in which measurements can be closely controlled. Currently used *in vitro* systems cannot accurately predict the efficacy of sunscreens because they ignore skin surface phenomena as well as skin-sunscreen interactions which are important considerations in sunscreen testing.

Objectives

The objective of these experiements is to determine the relative effectiveness of several sunscreens over a range of frequencies in the UVB spectrum by using the *in vitro* technique of absorption spectroscopy. Because this is not an *in vivo* test, it will not provide absolute effectiveness, nor will it provide a protection factor (PF); however, it will allow you to compare one sunscreen with another in a meaningful scientific manner, and it circumvents federal regulations on using human subjects in laboratory experiments.

Two methods of *in vitro* testing are provided in this segment. The first, by comparison, is a rather time-consuming investigation requiring equipment which some students may have difficulty in obtaining. The results of this first investigation, however, will yield quantitative results of the effectiveness of various commercially available sunscreens.

The second method for sunscreen testing outlined in this segment is a much less involved study utilizing more readily available equipment and taking less time. The results of this second method are of less value since they are only qualitative.

The first method for sunscreen testing is recommended if the time and equipment are available.

METHOD 1: Absorption Spectroscopy with Monochromator

Materials

Samples of sunscreens

2 Quartz plates (glass microscope cover slides will substitute, but poorly)

Light source in the UVB range (commercial sunlamp, laboratory Hg vapor, Xe arc lamps, or "black light.)

Monochromator, designed such that increments of 1 to 5nm from 28nm to 320nm may be selected. (This is the entire UVB range.)

Photomultiplier sensitive in the UVB range, along with an appropriate power supply.

Ammeter in the mA and μA range.

A monochromator, in its simplest form, is an instrument similar to the "shoe box" spectrometer with two minor changes. (1) The monochromator has some mechanism for precisely rotating the grating, which has the effect of changing the position of the spectrum on the screen, and (2) instead of the screen, there is another slit, the exit slit. The exit slit is in the position at which you normally place your eye to view the spectrum. These two changes produce the effect of only being able to see one color or wavelength when looking into the exit slit, and by rotating the grating, you can select that wavelength.

The photomultiplier replaces the eye as an instrument for measuring spectral intensity of the light incident upon the exit slit. It produces an output current which is proportional to the intensity of the incident wavelength, and the ammeter is used to measure that output current.

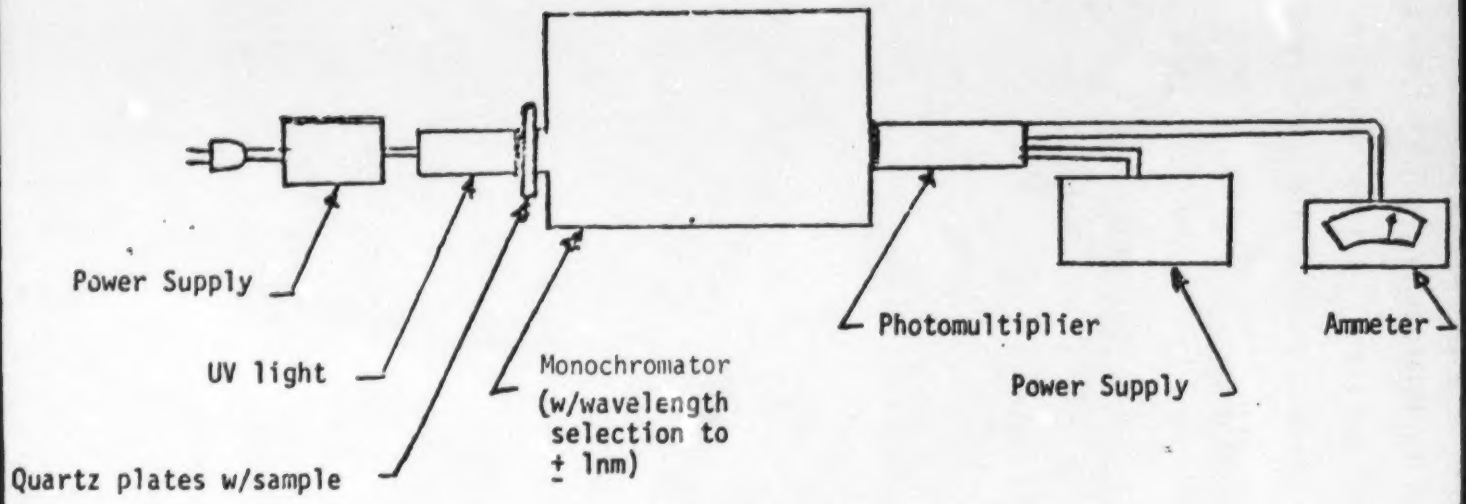


Figure 4.1

Apparatus for Determining Relative
Effectiveness of Sunscreens

Procedure (See Figure 4.1)

As explained earlier, the radiation from 286nm to 320nm significantly passes through our atmosphere and is harmful to the skin. This is likely to be the range you will want to investigate. Starting the monochromator at the 286nm setting, and incrementing one to five nanometers for each reading, determine the amount of current produced for each reading using only the quartz plates in the light path. The relative intensity at each wavelength chosen will greatly depend upon the emission spectrum of your light source. You will likely find large variations in the current from reading to reading. These unfiltered readings will later be compared with those taken using the sunscreens as filters.

Once these are read and charted in the data table, you should take your first sample and place a small drop in the center of one quartz plate. Place the other quartz plate on top of the first and apply a pre-determined but reproducible force on the two plates. This is important so that the thickness of each sample will be the same. One way to obtain a standard "squeeze" might be to lay the pair of plates (with the drop of sunscreen between them) on a flat surface and (gently) place a weight on top. This same weight could then be used on each succeeding sample.

Now that the sample is prepared, take a series of readings, similar to the ones taken previously, and record. Do the same for any other sample you wish to test. A convenient way to record this data might be to use a chart like that shown in Table 4.1.

Wavelength nm	Current w/o filter (μA or mA)	Current w/Brand X (uA or mA)	Percentage Transmission Brand X	Current w/Brand Y (μA or mA)	Percentage Transmission Brand Y	Etc.
286						
287						
288						
.						
.						
.						
320						

Table 4.1

Chart for Recording Sunscreen Absorption Data

Analysis

(a) Make a graph of current vs wavelength for each sample and for the readings with no sunscreen. The pattern formed by the data points should tell you which products did well and which did poorly.

(b) A better analysis of the data can be done with a little added effort, but will yield a more useful result.

Consider the unfiltered readings taken at each wavelength to be equal to 100% (transmission of light). Then calculate the percent transmission of each sunscreen at each wavelength. This is done by dividing the current read with a sunscreen filter by the current read with no filter, and multiplying by 100%. These values can then be plotted on a graph of percent transmission vs wavelength. Obviously each of the data points for the unfiltered readings would form a straight horizontal line at the 100% position. The others would form a pattern by which you could readily determine the range of wavelengths where the greatest percentage of filtering occurs.

Sample:

At 295nm the current with no filter was 860μA, and with Brand X the current was 215μA. On your graph you would plot 100% for the unfiltered reading at 295nm and

$$T = \frac{215}{860} \times 100\% = 25\% \text{ transmission}$$

25% for the Brand X at 295nm.

A projection factor corresponding to a particular wavelength (PF_λ) can be defined as follows:

$$PF_\lambda = \frac{1}{T} \times 100\%.$$

From the above example, the $PF_\lambda = 4$, however, this is for a particular wavelength and should not be confused with the definition of PF as determined

by <u>in vito</u> test. Also the PF_λ does not take into account all the wavelengths in the UVB spectrum.

At this point you could further modify the protection factor to include several wavelengths in the UVB spectrum. For example:

$$PF_{ave} = \frac{\sum_{\lambda} I_0(\lambda)}{\sum_{\lambda} I(\lambda)}$$

where $\sum_{\lambda} I_0(\lambda)$ means the sum of the ammeter readings at a selected number of wavelengths in the UVB region (290 to 320nm in 5nm increments), without the sunscreen and $\sum_{\lambda} I(\lambda)$ are similar readings with the sunscreen between the quartz plates.

Use your data to calculate a PF_{ave} by the above definition, and compare your values with the PF provided by the manufacturer. Your PF_{ave} will probably be higher than the manufacturer's PF. Can you list several reasons as to why this might be the case?

METHOD 2: Absorption Spectroscopy With Shoebox Spectroscope

MATERIALS

Sunscreens

Several glass microscope cover slides.

UV light source - Hg vapor lamp, Xe arc lamp, or "black" light

Shoebox spectroscope.

This method employs visual observations of the UV spectrum as opposed to the irradiance (current) measurement made in Method 1. The arrangement of equipment for the observations is illustrated in Fig. 4.2.

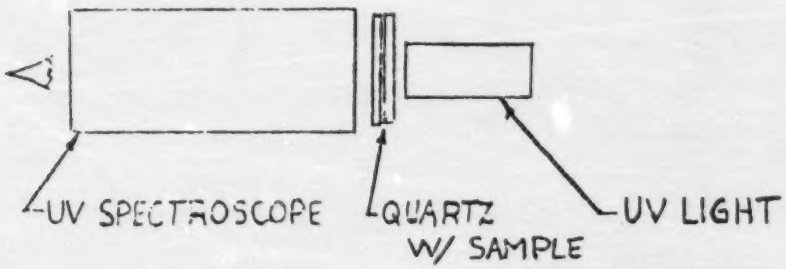


Figure 4.2

Equipment for Observing UV Absorption Spectrum

Sample preparation is the same here as in Method 1; however, the glass microscope cover slides can be used so that several samples can be prepared and available for observations at the same time. Two slides without a sunscreen between them will be used as a reference.

Glass cover slides can be obtained from laboratory equipment supply houses such as Fisher. They vary in thickness from 0.15 to .25mm, and are not strong absorbers at these thicknesses. (If the cover slides are not available, you can try cellophane which is a common wrapping material; however, care should be

taken to try to make all samples of equal thickness.)

Observations are made by comparing the UV spectrum when the reference (slide without sunscreen) is in the light path, to that when a sample is in the light path. This can be accomplished by having the equipment arranged so that your hands are free to hold or manipulate the samples.

You may observe that the intensity of the UV spectrum, as seen on the fluorescent screen, is less when a sample is in the light path as compared to the reference. If this is not the case, then qualitatively, the sample is not a good sunscreen.

A qualitative comparison can also be made between several sunscreens by a process of elimination. For example, if sample "B" is a better absorber than "A", but "A" is better than "C", then the ordering in effectiveness would be "B", "A", and "C". Ordering of this type can be done for all your samples.

You can compare your ordering of samples with that of the PF's given in Table 3.2.

As a further investigation you can observe the UV absorption spectrum of any substance you might think would serve as a sunscreen. For example, one of the authors (PNH), while a college student, made a sunscreen by dissolving iodine in mineral oil. Here's your opportunity to invent and test a sunscreen.

SEGMENT V SUMMARY AND DISCUSSION QUESTIONS

The purpose of this final segment is to briefly review that material which has been discussed, present questions to evaluate the reader's comprehension of the material and finally to present topics of further study to encourage research beyond the scope of this module.

The central issue of this module, as pointed out in the introduction, relates to a widespread lack of awareness of the harmful effects of solar radiation on the skin. Further, there appears to be limited knowledge on how damage may be prevented, and on the validity of claims made by manufacturers of sunscreens.

To properly cover the issues of this module, a few basic principles of electromagnetic radiation needed to be presented. In Segment I, some wave properties of light were discussed. It was pointed out that, although light is not a wave in the mechanical sense of the word, it does exhibit wave properties, including having a measureable wavelength and frequency, and diffraction. Diffraction was utilized to measure wavelengths, with the aid of student built spectroscopes. These spectroscopes allowed the reader to analyze both sunlight and various lab sources of light, by dispersing light into its corresponding spectrum. Through this process, the reader was able to see that a lab source of light (mercury vapor) might substitute favorably as a source of sunlight for in vitro testing of sunscreens.

Before actually proceeding with the sunscreen tests, information concerning the atmosphere's role as a solar filter was discussed. This process was described to give the reader a realistic assessment of radiation intensities near the earth, and to point out, as a related issue, the atmosphere's importance to our survival.

In Segment III, the reader's attention was directed toward the anatomy of human skin so that a better understanding of potential solar damage might be achieved. This information was provided to help stress the importance of this module's central issue. It was felt that some background material on skin anatomy, and a follow-up description of the cell damage which accompanies overexposure to the sun, would give the reader a realistic view of the importance of protection. To further emphasize this point, some data on cancer incidences vs. approximate exposure durations was presented. This evidence clearly illustrates that a great deal of damage may result from solar radiation.

Following this background information, two lab experiments, one qualitative and one quantitative, were presented in Segment IV to aid the student in comparing the effectiveness of various sunscreens through in vitro testing. Using an acceptable UV light source with known wavelengths of light (as determined in Segment I), the student was instructed to compare the filtering of several sunscreens at a variety of wavelengths and then calculate the percent absorption of each. This provided a reasonably valid qualitative comparison of each sunscreen's effectiveness. Various references were provided so that student results might be compared with other research. This lab experiment helped fulfill a secondary objective in this module--to aid the development of skills needed for productive research. As was pointed out in the introduction, society depends heavily on the role of the research scientist, and the scientist has a duty to report his conclusions to society. It is assumed that a student will improve his researching skills through this laboratory exercise.

For Further Study

The topics and issues of this module call to mind a wide spectrum of related topics and issues worthy of further research. Listed below is a partial accumulation of these topics along with a brief description of each. It is hoped that some of these topics become the basis for further study by some of the readers.

1. "Sunscreens" were frequently referred to throughout this module. We defined a sunscreen as a substance, which by reflection or absorption, blocks the sun's UV radiation from the skin and thus prevents damage to a greater or lesser degree. What about products advertised as "suntan lotions" or "suntan oils"? Manufacturers often make claims of products which promote a suntan. Either directly claimed, or at least implied, by these manufacturers is that there are "tanning rays" and "burning rays" emitted by the sun (presumably different wavelengths) and that their products allow only the tanning rays to reach the skin. Some of our research (see References 6, 9 in Segment III) strongly suggest that there is no such thing as tanning rays and that a lotion which "promotes a suntan" is impossible. Who is right? What does the most recent literature say concerning suntan lotions? If recent evidence continues to suggest that suntan lotions do not meet their claims, should they be banned? Should they be forced to restate their advertising claims so as not to mislead the consumer?

2. The Food and Drug Administration (FDA), a federally funded organization, has the responsibility of approving various foods as well as prescription and non-prescription drugs for consumer use. Should the FDA be involved in the issue of sunscreen effectiveness? Should minimum standards be set by the FDA (such as a minimum Protection Factor) in order for a substance to be

sold as a sunscreen? You might again consider the issue raised in the previous question concerning suntan lotions. Should the FDA have some say in whether or not manufacturers can sell a product claimed to promote suntans, if, in fact, it really does not?

3. Recently there have been various "tanning salons" springing up throughout the country. The promoters claim that in a few minutes time you can give yourself a uniform tan. Subscribers to the service are encouraged to return on a regular basis (with money, of course) to maintain this tan. The lights used in the salons are a UV source of radiation. There is monumental evidence (as seen in this module and in many of the references provided) that UV radiation leads to premature aging of the skin and various forms of skin cancer. Despite all of this, the promoters claim that their treatment is harmless. Can this be true? Should there be laws governing the intensities and exposure time of UV allowed?. Should they be altogether banned, or be required to post a sign similar to those posted on cigarette packages warning the customer of danger? (Did posting the sign on cigarette packages do any good?)

4. A topic relevant to this module, but not covered, is the process by which sunscreens actually work. As you may recall from Segment III sunscreens can roughly be divided into two categories, physical and chemical. Consider the chemical sunscreens. How do they filter the harmful radiation from the sun? What sort of reaction occurs in the substance? What happens to the energy represented by the filtered UV? Is it converted to another, less harmful form of energy? Is the process by which atmospheric filtering occurs (Segment III) similar to the process by which sunscreens filter?

5. In Segment II, ozone was mentioned as being a valuable atmospheric constituent for the filtering of UV radiation between 200 and 300nm. Despite our vital dependency upon ozone, we occasionally hear of various pollutants which are believed by some to be destroying it. Fluorocarbons in particular are considered to be among the most harmful substances to the ozone layer. Find some recent information on this topic. Have fluorocarbons been proven to be damaging? Are there other substances in common use which are potentially damaging? What government restrictions currently exist to either control or eliminate production of ozone destroying products? What is the chemical reaction between ozone and fluorocarbons (or other substances) which destroys the ozone? Can ozone be somehow produced and "placed" back in the atmosphere?

6. In Segment I, the reader was instructed to use fluorescent paint on a piece of tissue paper so that incident UV radiation would be observable. Fluorescence is a property of certain materials to absorb invisible UV radiation and re-emit part of the absorbed energy as visible light. What causes a material to be fluorescent? How does this process occur? (Is it a chemical reaction of some sort?) What substances have the property of fluorescence?

7. Although this module concentrated upon the harmful effects of solar radiation on the skin, there are most certainly beneficial effects. Besides the obvious benefits of warmth, light for vision, the sun acts to synthesize Vitamin D in the skin and helps cure certain diseases. A rather extensive article on the beneficial effects of solar radiation can be found in an article by Richard J. Wurtzman in Scientific American, Volume 233, Number 1, (July, 1975).